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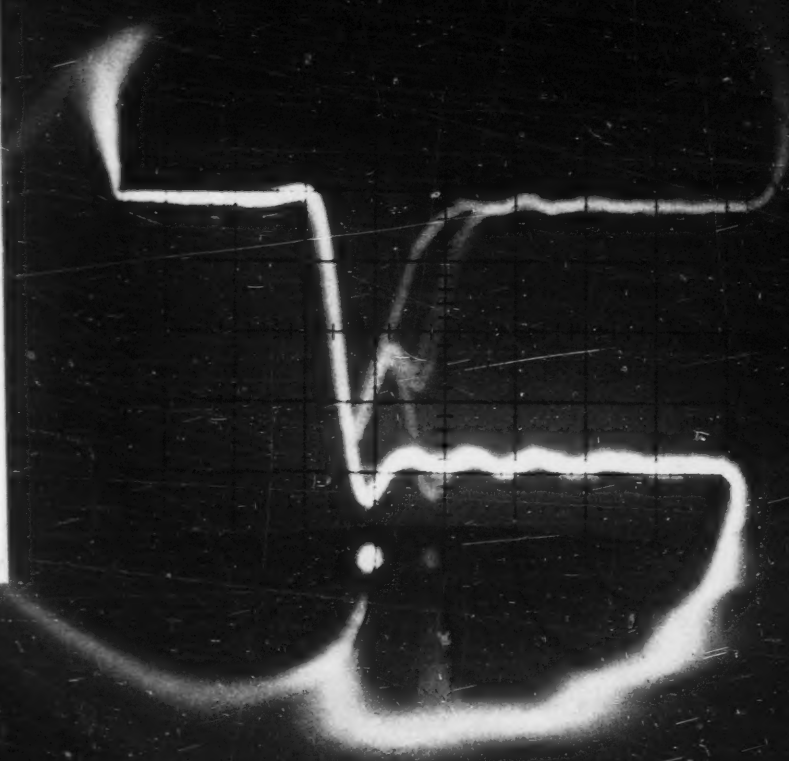

New materials and their uses

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CIRCLE **101** ON INQUIRY CARD

Future looks bright for high-performance ceramics

Recent R&D advances are making these materials practical as metal replacements, particularly in automobile engines.

Judith P. Sen
Strategic Analysis Inc.

ALTHOUGH THE USE of ceramics to fabricate products is several thousand years old, developments within the past 10 years have created enormous interest in the field and have led some observers to declare that we are on the verge of a second "stone age."

Interest is focused not on the traditional ceramic materials that are used in such familiar products as dishes, sinks, tiles, and bricks but, rather, on a class of ceramics known as engineering, technical, or, as they will be called here, high-performance ceramics.

Ceramics are defined as nonmetallic, inorganic materials that are processed with heat and/or pressure. High-performance ceramics are made from raw materials whose compositions are carefully controlled. These materials include boron nitride, boron carbide, sialon, silicon nitride, silicon carbide, and zirconia.

Depending upon the specific type of high-performance ceramic, these materials offer many desirable benefits including the ability to withstand high temperatures, resistance to corrosion, special electrical properties, special optical properties, wear resistance, hardness, strength, and biocompatibility.

For example, the hardness and wear resistance of some high-performance ceramics allow them to be used in cutting tools and bearings. Resistance to chemical attack has led to use in chemical processing plants as seals, valves, and pump components. Electrical properties make these materials useful in capacitors and piezoelectric devices, as substrates for integrated circuits, and as packaging for electronic devices.

Worldwide sales of high-performance ceramics are estimated to have been $5.2 billion in 1985. Packages and substrates for microelectronic devices accounted for $1.7 billion and capacitors for $1 billion.

The outlook for present applications is strong. The estimated overall growth rate is projected to be 16% from 1985 to 1990. Among the more dynamic segments are sensors with a projected growth rate of 28% per year, structural ceramics with 25%, and cutting tools with 20%.

This large existing market, with its attractive growth rates, is one of the reasons for the current intense interest in these materials. However, there are several other reasons.

A key consideration is the market for ceramic automobile engines. Although it is estimated that significant commercialization is at least another five years away, the market for high-performance ceramics in automotive applications is potentially worth several billion dollars. In contrast, 1985 worldwide sales of ceramics for automotive applications, excluding spark plugs, were roughly $180 million.

Reasons for using ceramics in automotive applications include both the functional and structural properties of the materials. Functional properties include electrical, magnetic, and chemical. Functional components currently being manufactured with high-performance ceramics include oxygen sensors, knock sensors, thermal sensors, fuel level switches, and spark plug insulators.

The important structural properties required for automotive applications include the ability to maintain structural integrity under high temperatures while hav-

ing densities that are less than those of the metals they replace. Structural components now being used include catalyst supports and ceramic fibers for fiber-reinforced metal pistons.

Examples of engine parts now in use are exhaust port liners for the Porsche 944 Turbo and turbine rotors for the Nissan "Fairlady." Isuzu Motors is using silicon nitride glow plugs and precombustion chambers. Isuzu has a policy of incorporating at least one new ceramic part into its cars each year.

New engine systems under development include adiabatic diesel engines and the automotive gas turbine. Adiabatic engines do not require a cooling system and thus are more efficient because combustion heat is not lost through cooling. In addition, the weight of the cooling system is eliminated, as is the need for cooling system maintenance. In an experimental adiabatic engine developed by Cummins Engine Co., ceramics are used as coatings for cylinder walls, cylinder heads, piston tops, and valve seats.

Gas turbines generate power by driving a rotating turbine with compressed high-temperature gas. Gas turbine rotors made of a high-performance ceramic, such as silicon nitride or silicon carbide, can be operated at 1400 C as opposed to metal superalloys which are limited to 1100 C. Ceramic turbines are expected to be 30% more fuel efficient than are conventional piston engines.

The U.S. Dept. of Energy has been supporting two major demonstration projects involving gas turbines that contain ceramic parts. In one project, researchers from Ford Motor Co. and Garrett Turbine Engine Co. are developing a 100-hp single-shaft engine. The engine has parts made with silicon nitride, silicon carbide, and lithium aluminosilicate. These parts include the turbine assembly, combustor liner, and flow-path housing.

In another automobile gas turbine project, scientists at General Motors Corp. are developing a 100-hp two-shaft engine. Using two shafts reduces the strain on each turbine rotor, allowing use of a wide range of ceramic materials.

Important materials for automotive applications are silicon nitride, silicon carbide, and partially stabilized zirconia. Silicon nitride offers high strength resistance to thermal shock and low thermal expansion, and it serves as an insulator. Silicon carbide is very hard and is a good heat conductor. Partially stabilized zirconia is a very strong material that is unusually resistant to catastrophic cracking within certain temperature limits.

The most general problems are reliability during use, reproducibility in production, and the cost of production. Reliability refers most specifically to the problem of ceramic brittleness.

The brittleness of ceramic materials, *i.e.*, their susceptibility to catastrophic cracking, has been a major drawback to commercialization. The brittleness problem is being approached by improving the properties of raw materials and also by improving processing techniques. Changes that have been made in raw materials include preparing materials at high levels of purity, introducing various additives, and making fine, highly uniform powders.

Among the processing techniques under investigation are hot isostatic pressing, injection molding, and slip casting. Hot isostatic pressing (HIP) reduces the porosity that is responsible for weakening the ceramic but requires long cycle times.

Injection molding allows rapid formation of complex shapes, but tooling costs are high and total volume is limited. Slip casting is suitable for producing complex shapes and tooling costs are low. Drawbacks to slip casting are long cycle times, limited volumes, and high labor intensity.

The problem of production reproducibility refers to the difficulty of achieving uniform physical properties not only from batch to batch, but within single batches. The lack of reproducibility is a major contributor to the high cost of manufacturing products from high-performance ceramics.

Another cost factor is the expense of finishing products. The hardness of high-performance ceramics can lead to complex, time-consuming machining or expensive grinding.

One final drawback is the lack of experience designers have with ceramics in the end-use industries. A major effort will be required to educate designers to

Estimated worldwide sales of high-performance ceramics, 1985

Product	U.S. dollars (billions)
Packages and substrates for microelectronic devices	1.7
Capacitors	1.0
Ferrites	0.9
Cutting tools	0.8
Piezoelectric devices	0.3
Structural ceramics	0.3
Thermistors, varistors	0.2
Total	5.2

Projected U.S. growth of selected high-performance ceramics

Product	Average annual growth 1985 to 1990
Gas and humidity sensors	28%
Structural ceramics	25
Cutting tools	20
Capacitors	14
Ferrites, resistors, and piezoelectric devices	14
Packages and substrates	10

Significant growth in automobile engine parts will begin after 1990.

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accept these materials and to design products to take advantage of ceramic properties.

Despite the problems, the market potential is recognized not only by companies that traditionally have been active in the ceramic area but also by many firms outside the ceramic industry that have become aware of the opportunities and are eager to participate.

Companies now involved in advanced ceramics research include established traditional ceramic firms, established advanced ceramic firms, small entrepreneurial firms, and large nonceramic companies that wish to diversify into advanced materials.

Participation in the industry can include supplying raw materials, processing ceramic shapes, making fully assembled parts, or combinations of these activities.

Corning Glass Works and Norton Co. are examples of established ceramic companies adapting traditional technology to new areas. Companies such as AVX Corp., Coors Porcelain, and National Beryllia are established firms completely devoted to advanced ceramics. Small entrepreneurial companies include Adiabatics and Lanxide. Among the large nonceramic companies entering the business are Honeywell Inc., Brunswick Corp., and Standard Oil of Ohio.

Awareness of the opportunities in high-performance ceramics has been spurred in part by the enormous effort taking place in Japan. Japan's Ministry of International Trade & Industry (MITI) has targeted the development of advanced ceramics as part of a national technology policy. Approximately 150 Japanese companies are involved in some kind of high-performance ceramics manufacturing activity, although in many cases these products represent a fraction of total sales.

Currently, Japan is recognized as a leader in the use of ceramics for electronic applications. For example, Kyocera is the world's largest producer of packages for integrated circuits. Other active Japanese companies include Toray, NGK Spark Plug, NGK Insulators, Hitachi, and the automobile manufacturers.

The high-performance ceramics industry is experiencing a period of rapid change. Although major increases in consumption may be a decade or more away, many companies are convinced of the enormous potential of the business and believe that obtaining future rewards will require taking risks now. No one is certain exactly what the industry will be like in 10 or 20 years, but many companies are determined to be active when the market for high-performance ceramics is fully developed. R&D

THE AUTHOR

Judith P. Sen is a project manager with Strategic Analysis Inc., Reading, PA, an international consulting firm. Sen received an MBA at Univ. of Pennsylvania, Wharton School, Philadelphia, and a PhD in inorganic chemistry at Stanford Univ., Palo Alto, CA.